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**THE EFFECT OF COATING LUBRICANTS ON
BOXBOARD HOT-MELT GLUEABILITY**

BY

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**A Thesis submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree**

**Western Michigan University
Kalamazoo, Michigan**

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ABSTRACT

Coating lubricants are commonly used in the folding boxboard industry to reduce dusting, improve gloss, increase dried coating flexibility, and modify coating slurry viscosity. Hot-melt adhesives are becoming increasingly popular among boxboard converters due to the strong bonds developed with very little set time. Very little is known about the interaction between the lubricants on the coating surface and adhesion developed with hot-melt adhesives.

In this study 100% recycled boxboard was coated on an air knife coater with a base coating and with 1%, 2%, 4%, and 8% calcium stearate and polyethylene glycol lubricants. The board was tested for Gardner gloss, water drop contact angle, static slip angle, and hot-melt glueability. Gloss results indicated a larger dependence on finishing conditions rather than lubricants. Static slip angle results were inconclusive. Contact angle and glueability testing indicated a possible relationship between increasing contact angle resulting in decreasing glueability.

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INTRODUCTION

Coated boxboard converters utilize hot-melt adhesives to increase the strength of the glue bonds necessary in box production and increase the speed at which the bonds can be made. Coating lubricants are used in boxboard coating to increase gloss, reduce dusting, and increase pick strength of the coated board. Coating lubricants migrate to the surface of the coating and may affect possible adhesion development.

Little work has been done to examine the interaction between coating lubricants and hot-melt adhesives. This study examines the effects of two common coating lubricants, calcium stearate and polyethylene glycol, on the glueability, water drop contact angle, static slip angle, and gloss of coated board. These lubricants were added to a common base coating and applied at 1%, 2%, 4%, and 8% on pigment levels to 100% recycled boxboard and tested. The results are graphed and analyzed and recommendations for further work are offered.

THEORETICAL DISCUSSION

Adhesion and Bond Strength

The production of glue bonds with adequate strength, as measured by destructive testing, requires conditions favorable to adhesion development. Petke (1) defined the difference between adhesion and bond strength as follows. Adhesion concerns interfacial factors and the interactions that lead to the formation of a bond. Interfacial factors include dispersion forces, wettability, miscibility of the adhesive and adherend, weak boundary layers, chemical bonds, and electrostatic attractions.

Bond strength is defined by the amount of force required to destroy the bond. Bond strength is influenced by these interfacial factors, but is also influenced by bulk property effects. These bulk property effects include bond geometry, joint configuration, residual stress, stress concentrations, and adhesive and adherend rheology and tensile properties. Bond strength is a sum of interfacial and bulk property effects, and the bulk factors usually predominate.

Contact Angle

Janes (2) reviewed several adhesion investigations and stated that most believe that the most fundamental prerequisite for good adhesion is uniform and unlimited

molecular contact between adherends. The amount of contact between adherends is determined by the wettability of the adhesive and the receptivity of the substrate. A measure of substrate surface receptivity is contact angle of a water drop with the surface.

Figure 1. illustrates the equilibrium contact angle between a water drop and a solid surface. The interfacial tension expressed by Young's equation is (2)

$$V_{sv} = V_{sl} + (V_{lv}) * (\cos \theta)$$

Where: V_{sv} = solid and air interface tension
 V_{sl} = solid and liquid interface tension
 V_{lv} = liquid and air interface tension
 θ = contact angle

As the contact angle decreases, the wettability of the system increases, promoting greater surface contact. The increased contact area allows additional areas for adhesion to develop, increasing bond strength. In general, a lower contact angle will allow greater spreading of the adhesive over the substrate, increasing the adhesion and bond strength.

Adhesion Mechanisms

Mechanical Theory

According to the mechanical theory of adhesion, the

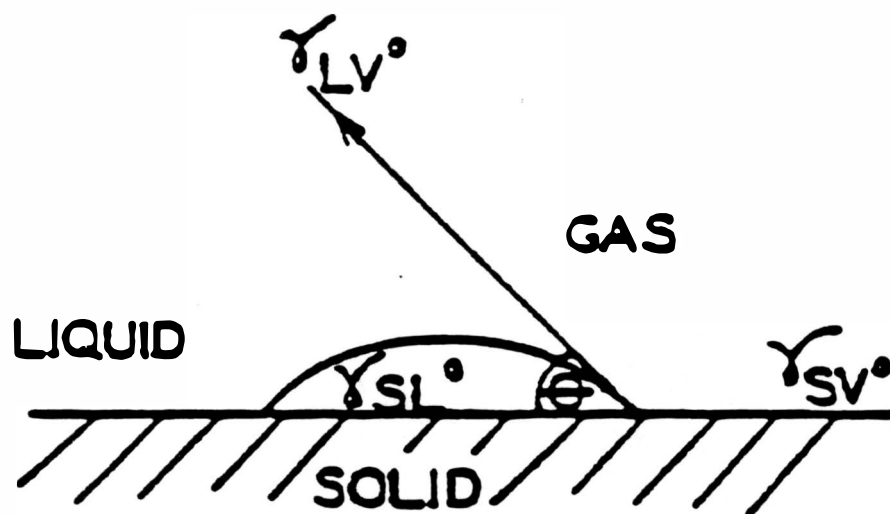


Figure 1. Water Drop Contact Angle

mobile adhesive penetrates into the pores of the substrate and becomes immobile, locking the adhesive into the substrate. The amount of penetration of the adhesive into the substrate limits the adhesion developed and therefore the bond strength attainable. The amount of penetration is affected by the amount of time the adhesive is mobile, adhesive viscosity, amount and depth of pores in substrate, the area of the bond, and the wettability of the substrate by the adhesive.

Petke (1) states that very few uses of mechanical adhesion occur in which adsorption of the adhesive onto the substrate and intermolecular forces are not factors. Janes (2) reviewed results from several mechanical adhesion experimenters and stated that specific adhesion through intermolecular forces is of greater importance than mechanical adhesion, even in a system where considerable penetration of the adhesive is present. Mechanical adhesion definitely occurs in a porous substrate such as paper, however the contribution of this mechanism to overall bond strength is considered secondary to other adhesion mechanisms.

Diffusion Theory

The diffusion theory of adhesion involves penetration of the adhesive into the substrate at the molecular level. The scale of penetration is many times smaller than that of

mechanical bonding and involves the intermingling of molecules of the adhesive and the substrate rather than the penetration of bulk adhesive into the substrate. Petke (1) states that dispersion forces play a large role in diffusion bonding, the degree of diffusion is determined by the cosolubility of the adhesive and substrate polymers and the bonding conditions.

The initial sharp boundary between the substrate and adhesive is gradually changed from pure substrate to pure adhesive over a distance of about 10 nm (100 Å). This makes the bond strength dependant on the adhesive/substrate mixture rather than one or the other.

Adsorption Theory

The adsorption theory requires very close contact, 0.3 nm (3 Å), between the molecules of the adhesive and substrate. If this closeness occurs, the molecules will attract and adhesion will occur. London dispersion forces, originating from the electron motion within the molecules, occur universally, allowing broad application of this theory.

The most important condition for maximizing adsorption is increasing the area of molecular contact as much as possible. Petke (1) states that the most important parameters affecting adsorption are wetting of the substrate by the adhesive, the degree of contact between adhesive and adherend, and the flexibility of the adhesive conforming to

the substrate surface.

Hot-Melt Adhesives

According to Casey (3) hot-melt adhesives are typically composed of a wax, synthetic resin, and plasticizer mixture. The quantitative ratio of wax to synthetic resin is used to control the tackiness or aggressiveness of the hot-melt. The amount of plasticizer controls the flexibility of the hot-melt after it has set.

Hot-melts are usually applied in the 150 to 250 F range to a room temperature substrate. Hot-melts are very fast setting, allowing little time for penetration into the substrate. They are being used extensively in the folding boxboard industry because their fast set time allows quicker production line speeds.

Coating Lubricants

Coating lubricants are utilized to alter the properties of the coating slurry and to obtain certain effects on the surface of the coated sheet. Lubricants affect the coating slurry by lowering the interfacial tension between clay particles. This allows more complete wetting of the clay particles, making the dispersion more fluid.

Lubricants are designed to migrate to the surface of the coated sheet, where they alter the properties of the coated surface. Lubricants make the surface of the dried coating

slipperier and reduce dusting by sealing the surface of the coating. Ink holdout and pick strength are also improved by this action.

Calcium Stearate

Calcium stearate has had widespread use because of its availability, economics, performance, and convenience. The melting point of calcium stearate is 320 F, well above the sheet temperature reached during drying and finishing coated paper and paperboard. This enables it to migrate to the surface of the coating in a controlled, dispersed form and perform its function at the coated surface. (4)

The primary reason for the success of calcium stearate is its unmatched performance as an anti-dusting agent. It is also claimed that addition of calcium stearate will provide greater surface flexibility, smoothness, and gloss. (5) Because of its high melting point it is theorized that calcium stearate migrates to the coated surface to lubricate any unbound pigment. The amount of lubricity realized is related to the average particle size of the calcium stearate utilized. The smaller the average particle size the greater the surface area. This larger surface area can impart more lubricity. (5)

Polyethylene Glycol

Polyethylene glycol lubricants are noted for lowering

coating slurry viscosity, improving sheet gloss, and less water drop contact angle increase. (6) Polyethylene glycol lubricants are available as slurries or powders. The molecular weight or polymer chain length of the polyethylene used has an influence on the properties exhibited by the coated sheet. Molecular weights under 4000 are preferred because of improved gloss development and lower slurry viscosity.

Studies on the performance of polyethylene glycol as a coating lubricant are not plentiful, but a comprehensive study by Kelly and Buttrick is summarized here. Their study compared three polyethylene glycols, low, medium, and high molecular weights, to a common calcium stearate. They found that polyethylene glycol lowered coating slurry viscosity while calcium stearate caused higher slurry viscosity. The medium and high molecular weight polyethylene glycols showed better gloss development and all polyethylene glycol molecular weights showed lower water drop contact angles and higher static slip angles.

EXPERIMENTAL PROCEDURE

Coating trials were performed using the pilot plant equipment in the Paper and Printing Science and Engineering Department at Western Michigan University. All coating was performed in one day and all testing was completed within two weeks. All laboratory testing, except for glueability, was done utilizing instruments at the Paper and Printing Science and Engineering Department laboratories. Glueability testing was performed at Waldorf Corporation's production laboratory in Battle Creek, MI.

Materials and Equipment

The substrate coated was 7 ply, 19 pt., 100% recycled boxboard. The board had two base liner plies consisting primarily of old corrugated containers for structural strength. The three filler plies of low quality raw material are primarily for bulk, adding little strength. The two top plies consisting of high quality white paper trimmings provide a smooth, high brightness printing surface after being coated.

The base coating was prepared in a sigma blade mixer using the formulation in Table 1. This coating formula was developed by examining several boxboard formulations and taking common elements out of all of them. It is intended to be a composite or generic formula. The #1 fine clay is used

Table 1. Base Coating Formulation

Component	Parts
#1 Clay	50.0
#1 Fine Clay	50.0
Titanium Dioxide	14.2
Latex #1	15.6
Latex #2	5.8
Defoamer	3.1
Alcogum	0.6
Ammonia	0.2

for coating strength and the #1 clay for gloss development. The titanium dioxide used was a rutile slurry. Latex #1 is a styrene-butadiene binder, Latex #2 is polyvinyl acetate. Both binder types are commonly used in the boxboard industry. One master batch of base coating was prepared for both lubricant trials. The lubricants used were also as generic as possible. A medium molecular weight of 4000 was used for the polyethylene glycol runs. This was to eliminate the effects of excessively long or short polymer chain length. The calcium stearate was received in a 60% slurry with a density of 8.9 lbs./gallon. The calcium stearate used was selected in the middle of manufacturer's offerings.

The hot-melt adhesive selected had medium aggressiveness and tackiness. It is utilized by several boxboard converters and commonly used a test adhesive.

The pilot plant coater was configured with a trailing blade and air knife for all runs. The blade pressure and air knife angle and flow were adjusted to apply a 9 lb./1000 sq. ft. coat weight on all runs. Speed was maintained at 350 FPM.

Procedure

The control sample, with no lubricant, was run first. When the coating conditions had stabilized and a sufficient amount of board had been coated, the remaining coating was removed from the coating pan. The coating was weighed and the amount of calcium stearate needed for the first calcium stearate run calculated. This amount was added and the coating was agitated for 15 minutes before being returned to the pan. This process was repeated as the percentage of lubricant was increased.

The entire coating pan and circulation system was cleaned before the polyethylene glycol runs were started. The same procedure was followed all polyethylene glycol runs.

Samples were cut from all runs and conditioned for 72 hours before testing. Samples were tested to determine Gardner gloss, water drop contact angle, static slip angle, and Waldorf hot-melt glueability. All testing except for glueability followed TAPPI Methods. Hot-melt glueability testing followed Waldorf Corporation's suggested method. See Appendix II.

RESULTS AND STANDARD VALUES

Table 2. lists averages, standard deviations, and percent standard deviations for gloss, water drop contact angle, static slip angle, and glueability testing. Appendix I outlines the test sample method used for glueability testing. All other sample sizes were taken from the appropriate TAPPI Method.

Gloss vs. Percent Lubricant, Figure 2., results showed calcium stearate giving overall higher gloss values at all levels tested. Calcium stearate gloss increased 15.5% as its level was raised from 0% to 1%, declined 6.8% from 1% to 2%, and then declined 8.6% from 2% to 8%. Polyethylene glycol gloss values showed almost no change from 0% to 1%, dropped 9.7% from 1% to 2%, and then rose 6.9% from 2% to 8%. All calcium stearate gloss values were higher than polyethylene glycol at all levels tested.

Glueability vs. Percent Lubricant, Figure 3., results revealed polyethylene glycol glueabilities greater than calcium stearate at all lubricant levels tested. Calcium stearate glueability showed almost no change from 0% to 1%, dropped 16.2% from 1% to 4%, then declined 17.2% from 4% to 8%. Polyethylene glycol glueability increased 13.1% from 0% to 1%, then declined 6.1% from 1% to 2%, and dropped 28.% from 2% to 8%.

Contact Angle vs. Percent Lubricant, Figure 4., testing showed all calcium stearate levels causing a greater contact angle than polyethylene glycol. Calcium stearate increase from 0% to 1% caused a 61.5% contact angle increase, a 10.7% increase was observed from 1% to 8%. Polyethylene glycol contact angle increased 53.8% from 0% to 1% and increased 6.4% from 1% to 8%. Polyethylene glycol contact angle values remained below calcium stearate values at all levels tested.

A Glueability vs. Contact Angle, Figure 5., plot showed polyethylene glycol glueability increasing slightly from 52 to 78 , and declining sharply from 78 to 84. Calcium stearate glueability did not increase at all with increasing contact angle and declined sharply from 84 to 93.

Static Slip Angle vs. Percent Lubricant, Figure 6., showed inconsistent results for both lubricants tested. No pattern or trend is apparent from this plot.

Table 2. Lubricant Trial Results**Gardner Gloss**

% Lubricant	Calcium Stearate		Polyethylene Glycol	
	Ave.	St. Dev.	Ave.	Std. Dev.
0	42.0	1.16	-	-
1	48.5	1.67	41.7	2.05
2	45.2	2.25	37.7	2.16
4	44.0	1.97	39.8	1.73
8	41.3	2.04	40.3	2.29

Glueability

% Lubricant	Calcium Stearate		Polyethylene Glycol	
	Ave.	St. Dev.	Ave.	Std. Dev.
0	175	4.90	-	-
1	173	7.12	198	8.02
2	145	5.33	186	5.86
4	131	7.74	168	6.39
8	120	6.32	134	5.66

Contact Angle

% Lubricant	Calcium Stearate		Polyethylene Glycol	
	Ave.	St. Dev.	Ave.	Std. Dev.
0	52.0	2.98	-	-
1	84.1	3.28	78.4	3.96
2	87.6	3.37	80.7	2.53
4	90.2	3.25	84.9	3.56
8	93.5	4.22	83.3	3.82

Static Slip Angle

% Lubricant	Calcium Stearate		Polyethylene Glycol	
	Ave.	St. Dev.	Ave.	Std. Dev.
0	28.5	4.22	-	-
1	34.5	5.06	36.0	9.24
2	32.0	7.84	32.0	8.01
4	32.0	2.06	32.5	8.78
8	31.5	10.22	36.6	5.97

Figure 2.

Gloss vs. Percent Lubricant

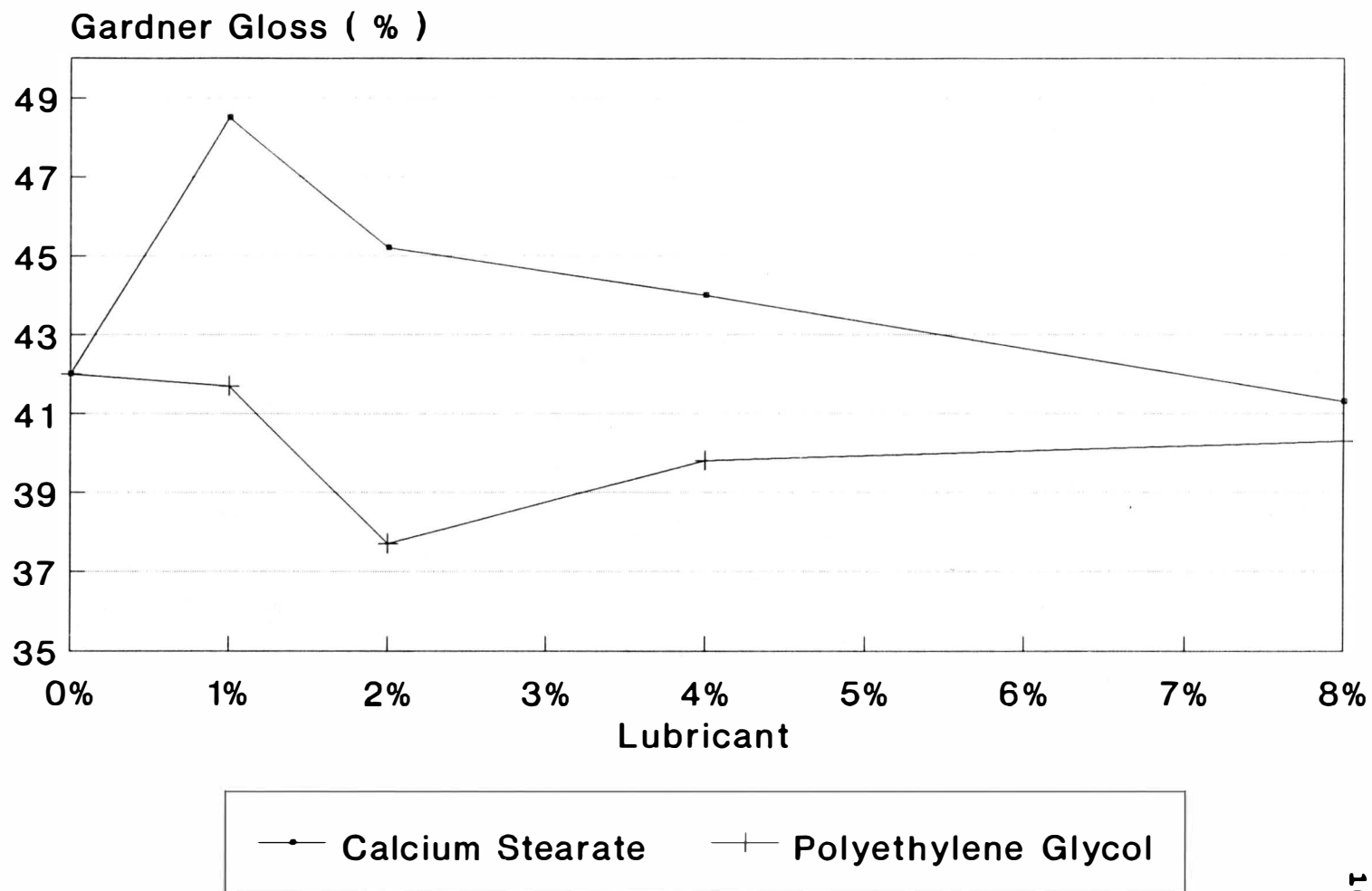


Figure 3.

Glueability vs. Percent Lubricant

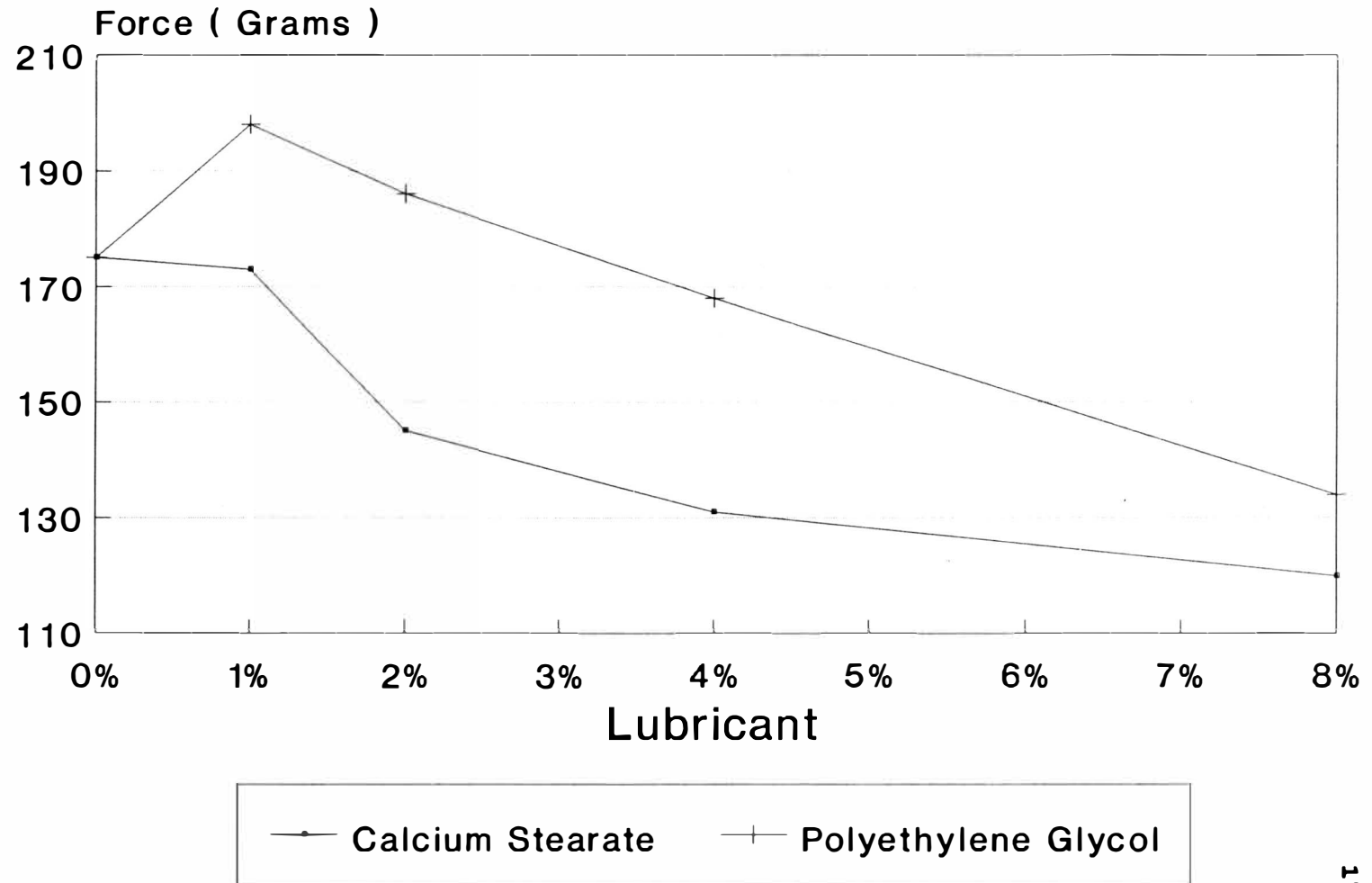


Figure 4.

Contact Angle vs. Percent Lubricant

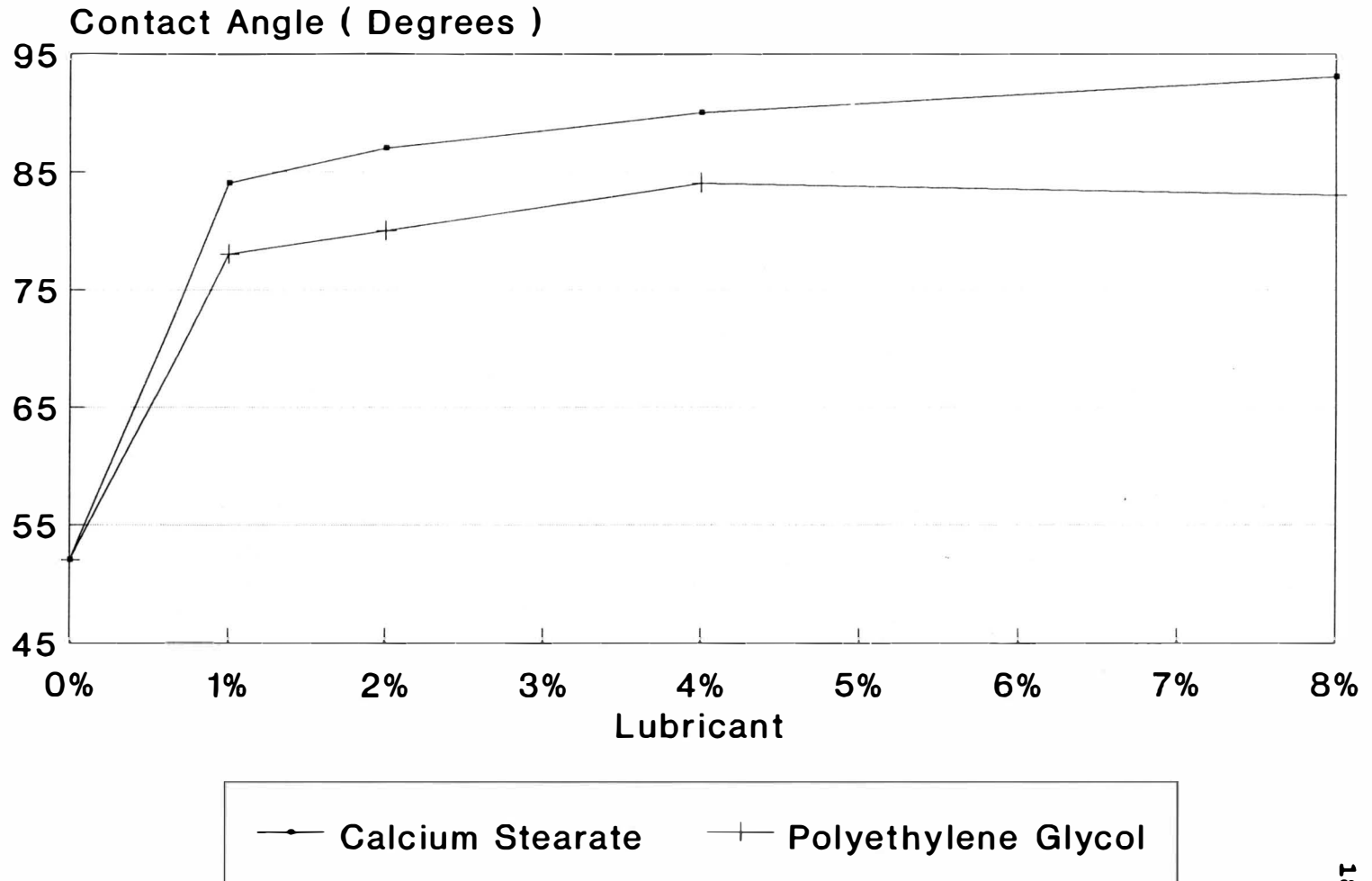


Figure 5.

Glueability vs. Contact Angle

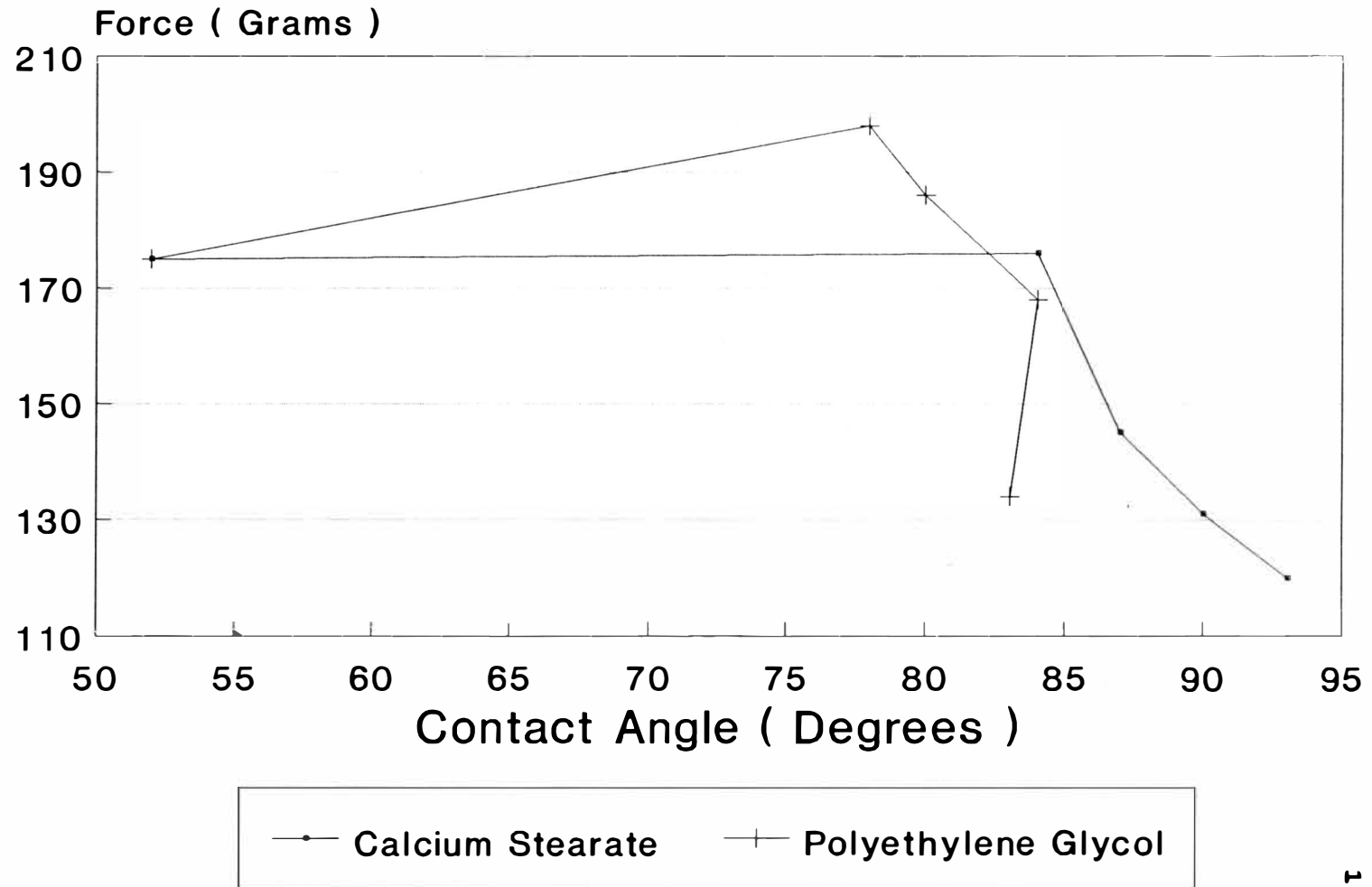
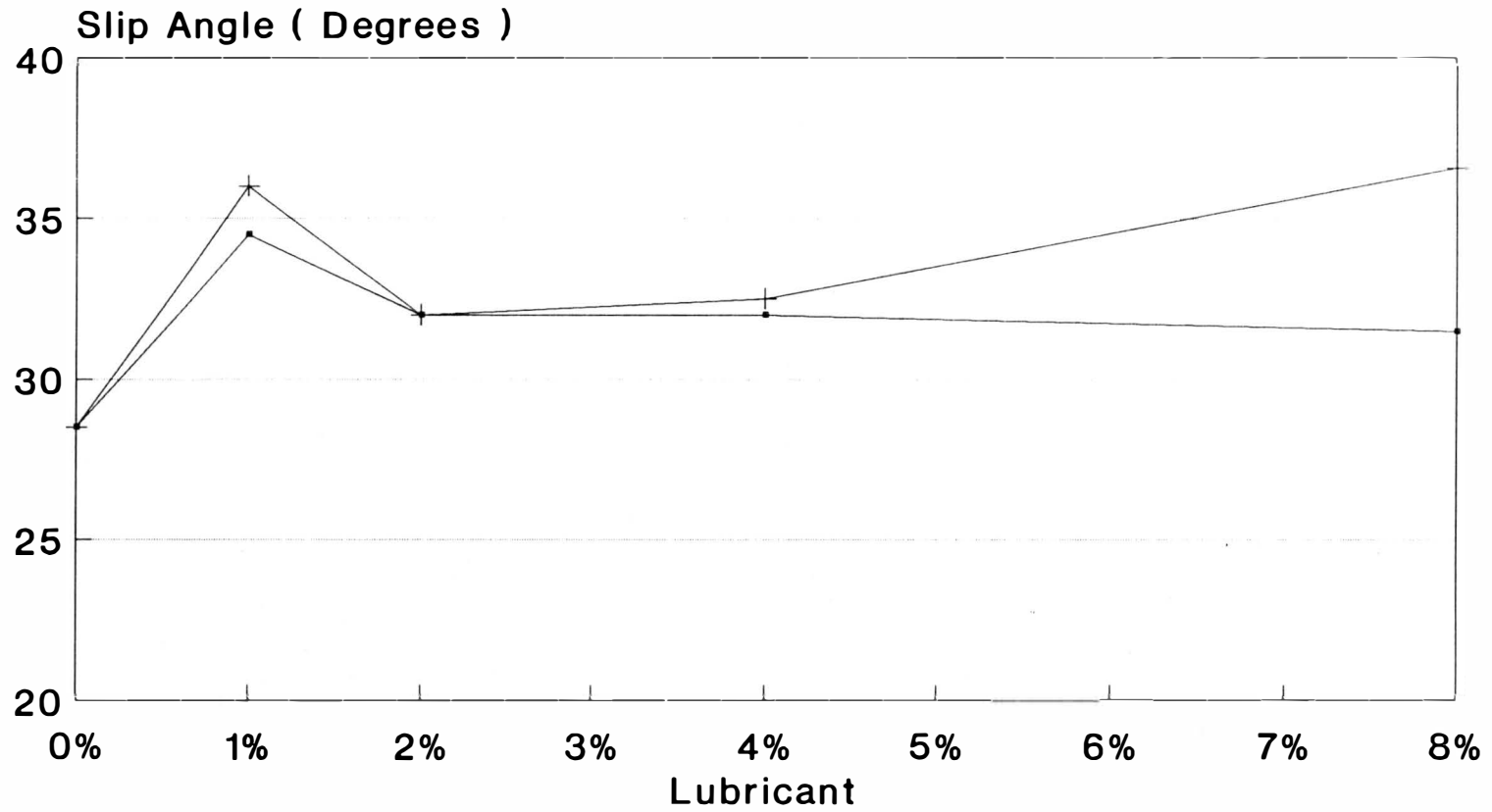


Figure 6.

Static Slip Angle vs. Percent Lubricant



DISCUSSION OF RESULTS

Gloss vs. Percent Lubricant results, Figure 2., demonstrated better gloss development at all lubricant levels for calcium stearate. Calcium stearate has a high melting point, above 320 F, so calcium stearate particles retain their integrity throughout the drying process. This could promote greater migration than if the particles were to break down. Although Kelly and Buttrick's study (6) indicated increased gloss with polyethylene glycol addition, a decrease in gloss was observed. This could be due to the difference in finishing conditions. Both Hern (4) and Kelly and Buttrick (6) supercalendered their samples, while no post-coating finishing was performed in this study.

Glueability vs. Percent Lubricant results, Figure 3., indicated better glue bond strength development for all polyethylene glycol samples tested. Polyethylene glycol actually increased glueability from the 0% to 1% addition levels before declining. All calcium stearate addition levels had an adverse effect on glue bond strength development. The integrity retained by the calcium stearate particles may have interfered with adhesion development at the coated surface.

Contact Angle vs. Percent Lubricant results, Figure 4., indicated calcium stearate addition caused a greater water drop contact angle increase than polyethylene glycol at all addition levels. This could be the result of better surface

sealing by calcium stearate particles that had migrated to the surface of the coating. Reduced polyethylene glycol migration could have disrupted the surface of the coating less, causing less of a contact angle increase.

The Glueability vs. Contact Angle plot, Figure 5., revealed a possible relationship between water drop contact angle and adhesion development. Glueabilities of both samples dropped sharply as contact angle increased. The reduced wettability of a surface with a high contact angle possibly influenced adhesion development. The fast setting hot-melt adhesive was prevented from coming into contact with as much of the surface as when the contact angle was lower. This prevented the same amount of adhesion by mechanical and adsorption mechanisms.

The surface of the coating was sealed more at higher contact angles preventing the adhesive from penetrating into as many interstices. This reduced the amount of mechanical adhesion development possible contributing to lower bond strength. The molecular closeness required for the adsorption mechanism to contribute to bond strength was also reduced. The adhesive was inhibited from spreading and maximizing the amount of surface contact. Increased surface contact increases the possibility of the close molecular contact required for adsorption to contribute to bond strength.

Static Slip Angle vs. Percent Lubricant results, Figure 6., revealed no clear trend or pattern. this was due

to incorrect execution of the test method. The interface created by the test should have been coating to back liner. Instead a coating top coating interface was tested. Interaction between the coatings at the interface probably caused the inconsistent results. Subjective observation of the samples revealed increased surface slipperiness as lubricant content was increased for both lubricants. However, no quantative test results proved this.

CONCLUSIONS

Gloss development results are possibly a function of finishing conditions. Finishing the coated board by supercalendering may have changed the amount of gloss development by both lubricants. Previous studies that have concentrated on the gloss development of lubricants have supercalendered and their results differed significantly. The particle size of the lubricants and the integrity these particles retain through the coating and finishing processes will likely affect final gloss development most.

Coating surface water drop contact was affected significantly by even low lubricant addition. The wettability of the coating surface was noticeably reduced in both cases by the lowest amount of lubricant tested. This indicated the possible presence of lubricant on the surface of the coating, the result of successful migration inducement. Lubricants are designed to migrate to the coating surface where their effects are intended to be noticed.

Glueability was affected by both the amount and type of lubricant used. This indicated the possibly large role lubricants have in determining the adhesive receptability of the dried coating surface. Although lubricants are used in small amounts, their presence at the coating surface while retaining their particle integrity, affects the surface chemistry of the coated surface greatly. Lubricants are

designed to make the surface slippery, adhesion development requires a surface with the opposite properties.

The response of glue bond strength to contact angle increase indicates the importance of maximizing surface contact to obtain adhesion development. The amount of surface contact developed determines the number of sites for any adhesion mechanism to contribute to bond strength. Mechanical and adsorption adhesion mechanisms are particularly dependent on increased surface contact to contribute to bond strength.

RECOMMENDATIONS

The focus of this study was not on gloss development, however, additional work in the area of gloss development contributions by lubricants is needed. Trials with lower lubricant levels and a variety of finishing conditions would most likely yield productive results. Correct execution of static slip angle trials in conjunction with trials using a coating/coating interface may reveal the nature of the coating/coating interaction that may have led to the inconsistent results in this study.

Trials at lubricant levels between 0% and 1% should give greater insight of the glue bond strength development. Sharp increases or decreases were the usual result of this study at those levels. Development of a curve using several lubricant addition levels between 0% and 1% would better illustrate the true effects of the lubricants on contact angle, glueability, and the relationship between them.

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APPENDIX I

HOT-MELT GLUEABILITY TEST PROCEDURE

1. Set the hot-melt tester to these conditions:

Bead Size	1 mm width, 4 - 6 in. long
Compression	35 PSI
Gun	55 PSI
Tank	60 PSI
Vacuum	20 PSI (as needed)
Delay	0.5 sec.
Dwell	0.5 sec.
Speed	140 FPM
Temperature	350 F
Nozzle Size	0.035 in.
Nozzle Height	0.375 in.

2. Add 50 grams of hot-melt to the glue pot for a fresh test. Allow 40 minutes for glue to reach operating temperature.
3. Cut samples from the carton side seam and the top and bottom glue flaps. For the first set of samples, these carton samples should be cut 3/4 in. wide by 6 to 9 in. long. To ensure uniformity of bond separation, apply scotch tape to the right hand portion of the top sample so that the tape will cover about 1 in. at the start of the bead. These pieces are attached, clay side down, to the base of the plunger by vacuum.
4. The bottom piece is cut from any other unscored area of the carton. Size is 2 1/2 in. by up to 9 in. This is set into the clip newsback side up.
5. Allow the bond to set a minimum of 30 sec. and a maximum of 90 sec. after mating. Then separate the bond with the TMI Slip tester.
6. Bonds should be made in sets according to the pattern on the next page.

SAMPLE SIZE FOR THE HOT MELT GLUEABILITY TEST

